Low mass dilepton production and chiral symmetry restoration

G. Chanfray

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[1] *IPNLyon, IN2P3-CNRS et UCB Lyon I, F69622 Villeurbanne Cedex*

We first discuss the possible manifestations of chiral symmetry restoration when hadronic matter is heated or compressed. This fundamental problem can be addressed through the in-medium behavior of hadronic spectral functions. I will focus in particular on the rho meson which can be studied with dilepton production in relativistic heavy ion collisions at CERN/SPS. Various theoretical approaches are presented in connection with the interpretation of experimental data. I will discuss in particular to which extent the broadening of the rho meson peak signals the onset of chiral symmetry restoration.

I. CHIRAL SYMMETRY : BREAKING AND RESTORATION

Asymptotic freedom and color confinement are usually considered as the most prominent properties of our theory of strong interaction, Quantum Chromodynamics (QCD). However QCD also possesses an almost exact symmetry, the $SU(2)_L \otimes SU(2)_R$ chiral symmetry which is certainly the most important key for the understanding of many phenomena in low energy hadron physics. This symmetry originates from the fact that the QCD Lagrangian is almost invariant under the separate flavor $SU(2)$ transformations of right-handed $q_R = (u_R, d_R)$ and left-handed $q_L = (u_L, d_L)$ light quark fields u and d : $q_R \to e^{i\vec{\tau}.\vec{\alpha}_R/2}\, q_R, \qquad q_L \to e^{i\vec{\tau}.\vec{\alpha}_L/2}\, q_L$.

The small explicit violation of chiral symmetry is given by the mass term of the QCD Lagrangian which is $\mathcal{L}_{\chi SB} = -m_q\,(\bar{u}u + \bar{d}d)$, neglecting isospin violation. The averaged light quark mass $m_q = (m_u + m_d)/2 \leq 10$ MeV, the scale of explicit chiral symmetry breaking, has to be compared with typical hadron masses of order 1 GeV, indicating that the symmetry is excellent and in the exact chiral limit ($m_q = 0$) left-handed and right-handed quarks decouple. From the associated left-handed and right-handed conserved currents, one usually introduces two linear combinations, the vector and axial currents :

$$\mathcal{V}_k^\mu = \bar{q}\,\gamma^\mu\,\frac{\tau_k}{2}\,q, \qquad \mathcal{A}_k^\mu = \bar{q}\,\gamma^\mu\,\gamma_5\,\frac{\tau_k}{2}\,q \tag{1}$$

The corresponding charges Q_k^V and Q_k^A commute with the QCD Hamiltonian. However at variance with the vector charges (which actually coincide with the isospin operators) the axial charges of the QCD vacuum are not zero : $Q_k^A|0\rangle \neq 0$. Hence the QCD vacuum does not possess the symmetry of the vacuum *i.e.* chiral symmetry is spontaneously broken (SCSB). This key property of the QCD vacuum is evidenced by a set of remarkable properties. SCSB manifests itself in the building-up of a chiral quark condensate : $\langle\bar{q}q\rangle = \langle\bar{u}u + \bar{d}d\rangle/2$ which mixes, in the broken vacuum, left-handed and right-handed quarks ($\langle\bar{q}q\rangle = \langle\bar{q}_L q_R + \bar{q}_R q_L\rangle/2$). The Gell-Mann-Oakes-Renner relation allows to show that it is large and negative : $<\bar{q}q>_{vac} \simeq$ -(240 MeV)^3, indicating strong dynamical breaking of chiral symmetry. SCSB is characterized by the appearance of (nearly) massless Goldstone bosons, to be identified with the pions. Finally, SCSB can be seen directly at the level of the hadron spectrum through the absence of parity doublets : the possible chiral partners (such as $\pi(140) - \sigma(400-1200)$, $\rho(770) - a_1(1260)$, $N(940) - N^*(1535)$) show a large mass splitting $\Delta M = 500$ MeV.

When hadronic matter is heated and compressed, initially confined quarks and gluons start to percolate between the hadrons to be finally liberated. This picture is supported by lattice simulations showing that strongly interacting matter exhibits a sudden change in energy- and entropy-density (possibly constituting a true phase transition) within a narrow temperature window around $T_c = 170$ MeV. This transition is accompanied by a sharp decrease of the quark condensate indicating chiral symmetry restoration. However far before the critical region, partial restoration should follow through the simple presence of hadrons. Indeed, inside the hadrons the scalar density, originating either from the valence quarks or from the pion scalar density (the virtual pion cloud), is positive hence decreasing the quark condensate. Said differently, the presence of hadrons locally restores chiral symmetry. This statement can be made quantitative since, to leading order in hadron densities, the condensate evolves according to [1,2]:

$$R = \frac{\langle\langle\bar{q}q\rangle\rangle(\rho_h, T)}{\langle\bar{q}q\rangle_{vac}} = 1 - \sum_h \frac{\rho_h \Sigma_h}{f_\pi^2 m_\pi^2}. \tag{2}$$

Each hadron species present with scalar density ρ_h contributes to the dropping of the condensate through a characteristic quantity Σ_h directly related to the integrated quark scalar density inside the hadron h : $\Sigma_h/m = \int_h d\mathbf{r}\,\langle h|\bar{u}u + \bar{d}d|h\rangle$. In nuclear matter the relevant quantity is the nucleon sigma commutator $\Sigma_N \simeq 45$ MeV. Putting the numbers together one finds a 35% restoration at normal nuclear matter density. The sigma commutator and the dropping of the chiral condensate can be estimated with effective theories in terms of the relevant degrees of freedom. It receives contribution from valence quarks, scalar field and virtual pion cloud. There is strong indication (from model calculations and analysis of photon data) showing that one major part of the nucleon sigma term comes from the pion cloud piece [3–5]: $\Sigma_N^{(\pi)} = \int_N d\mathbf{r}\langle N|m_\pi^2\,\vec{\Phi}_\pi^2/2$.

Despite the fact that the condensate is not an experimental observable, it is hardly conceivable that such a strong modification of the QCD vacuum should not have spectacular consequences on hadronic properties, namely on the hadronic spectral functions. A number of works have been devoted to the possible link between the evolution of the masses and the condensates using various models (sigma models , NJL model,..) most of the time at the mean field level. This activity has culminated with the universal scaling laws proposed by Brown and Rho, where hadron masses drop together with quark and gluon condensates [6]. However, the link between the evolution of the masses and the condensates cannot be an absolute one. For instance the pionic piece of the quark condensate does not contribute to the evolution of the mass [7]. It manifests in a more subtle way through the mixing of the vector and axial-vector correlators. More generally the modification of hadronic spectral functions is certainly not restricted to the shift of centroids of mass distributions. In that respect we have to study how chiral dynamics may generate a softening/sharpening or a broadening of hadronic spectral functions with some specific and highly debated examples (sigma, kaon, and rho mesons). The key question is the relationship between the observed reshaping and chiral symmetry restoration. One possible strategy to obtain this crucial connection is to make a simultaneous study of the spectral functions associated with chiral partners. A very important example is the rho meson and the axial-vector meson a_1 and we will see that there is a mixing of the associated current correlators trough the presence of the pion scalar density as already mentioned just above.

II. CHIRAL EFFECTIVE FIELD THEORY

To have some insight on the manifestions of chiral symmetry restoration and to make predictions, one has to rely on effective theories which should incorporate, as much as possible, the symmetry properties of the underlying QCD Lagrangian. One possibility is to introduce a chiral field under the form of a 2×2 matrix $W = \sigma + i\vec{\tau}\cdot\vec{\pi}$, where $\vec{\pi}$ and σ are identified with the pion and a scalar-isoscalar sigma meson. These fields transform into each other under chiral transformation (*i.e.* they are chiral partners) in such a way that their coupling to nucleons $\mathcal{L} = \bar{N}(\sigma + i\vec{\tau}\cdot\vec{\pi}\gamma_5)N$ is chirally invariant. The next step is to incorporate the dynamics of these chiral fields through the introduction of the kinetic energy and potential terms. Choosing a Mexican hat potential with parameters fixed by phenomenology (f_π,...) yields vacuum SCSB and the appearance of a chiral condensate $\langle\sigma\rangle = f_\pi$. The vacuum configuration corresponds to the bottom of the Mexican hat potential, the so-called chiral circle defined by $\sigma^2 + \vec{\pi}^2 = f_\pi^2$. Finally, One introduces an explicit symmetry breaking term $\mathcal{L}_{CSB} = f_\pi m_\pi^2\langle\sigma\rangle$ having the same algebraic properties than the QCD one, $\mathcal{L}_{CSB} = -2m\,\langle\bar{q}\,q\rangle$. By direct comparison one sees that the expectation value of the sigma field plays the role of the chiral condensate at the level of the effective theory.

An alternative formulation is obtained by going from the "Cartesian coordinates" $(\sigma,\vec{\pi})$ to the "polar coordinates" $(\theta,\vec{\phi})$ according to :

$$\sigma + i\,\vec{\tau}\cdot\vec{\pi} = \Theta\, U = (\theta + f_\pi)\; e^{i\,\vec{\tau}\cdot\vec{\phi}} \tag{3}$$

The new pion field $\vec{\phi}$ corresponds to an orthoradial soft mode which is automatically massless (in the absence of explicit CSB) since it is associated with rotations on the chiral circle without cost of energy. The new sigma meson field θ corresponds to a radial mode associated with the fluctuations of the "chiral radius". As demonstrated in [8], this chiral invariant θ field can be identified with the famous "sigma meson" of the relativistic QHD theories, thus giving a solution to the long-termed problem of their chiral status. To leading order in density and temperature, the dropping of the chiral condensate is given by :

$$R = \frac{\langle\langle\bar{q}q\rangle\rangle(\rho,T)}{\langle\bar{q}q\rangle_{vac}} = \frac{\langle\langle\sigma\rangle\rangle(\rho,T)}{f_\pi} = 1 - \frac{\langle\phi^2\rangle(\rho,T)}{2\,f_\pi^2} - \frac{|\langle\theta\rangle|(\rho,T)}{f_\pi} \tag{4}$$

The very important point, and this is the main lesson of this section, is that these two contributions to the dropping of the chiral condensate yield very different observable manifestations of chiral symmetry restoration. The pionic fluctuation piece ($\sim$ 20% dropping at $\rho = \rho_0$) is associated with axial-vector mixing and does not contribute to the dropping of the masses. This is the scalar piece ($\sim$ 15% dropping at $\rho = \rho_0$) which governs the evolution of the masses as a consequence of the shrinking of the chiral radius. To illustrate this statement, lets us give the in-medium evolution of some observables :

$$\frac{m_N^*}{m_N} = 1 - \frac{|\langle\theta\rangle|}{f_\pi}, \qquad \frac{m_\theta^*}{m_\theta} = 1 - \frac{3}{2}\frac{|\langle\theta\rangle|}{f_\pi}, \qquad \frac{f_\pi^*}{f_\pi} = 1 - \frac{|\langle\theta\rangle|}{f_\pi} - \frac{1}{3}\frac{\langle\phi^2\rangle}{f_\pi^2} \tag{5}$$

It can been seen explicitly that, contrary to the Brown-Rho scaling law (see eq.14 below), there is absolutely no universality in the evolution of the observables.

III. DILEPTON PRODUCTION AND THE RHO MESON

Low mass dilepton production has been reported as being among the evidences for the formation of a new phase of matter in relativistic heavy-ion collisions at CERN/SPS [9]. In particular the CERES collaboration [10] has observed an important radiation in the invariant mass region $300 - 700$ MeV/c beyond what is expected from the conventional sources able to explain the proton-nucleus data (fig.1). Since these conventional sources (the so-called hadronic cocktail) correspond to final state Dalitz decays ($\eta, \eta' \to \gamma e^+e^-$, $\omega \to \pi^0 e^+e^-$) and direct vector meson decays ($\rho, \omega, \Phi \to e^+e^-$), one can conclude that this excess of radiation originates from the interacting fireball before freeze-out. Due to the very large number of produced pions the first candidate is the $\pi^+\pi^- \to l\bar{l}$ annihilation process which is dynamically enhanced by the rho meson. Using vacuum meson properties many theoretical groups have included this process within (very) different models for the space-time evolution of $A - A$ reactions. Their results are in reasonable agreement with each other, but in disagreement with the data : the experimental spectra in the mass region $300 - 600$ MeV/c are significantly underestimated and the rho peak itself has the tendency to be overestimated as seen from fig.6. Thus one came to the conclusion that strong medium effects yielding a flattening of the spectra are needed. This has motivated a considerable theoretical activity that I will now briefly describe.

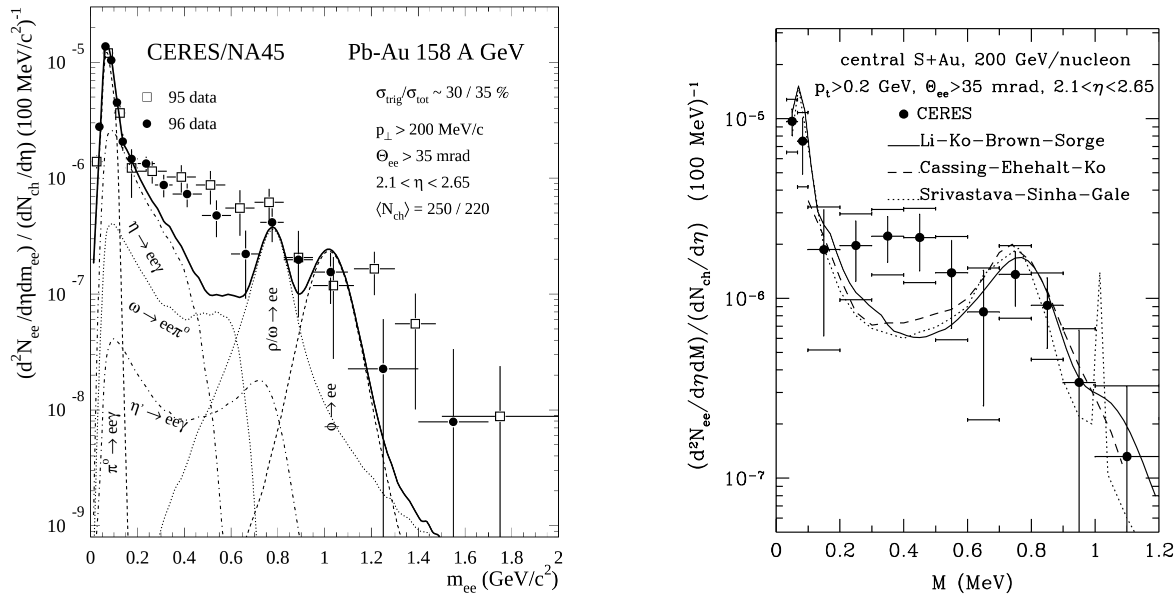

Figure 1

FIG. 1. Left panel : CERES/Na45 data on dilepton production data in central 158 AGeV Pb+Au collisions compared to a hadronic cocktail inferred from a thermal model. Right panel : Dilepton invariant mass spectrum measured in central 200 AGeV S+Au collisions compared with theoretical calculations incorporating $\pi\pi$ annihilitation with free space meson properties.

Dilepton production from hot and dense matter. The dilepton production rate (DPR) per unit 4-volume from a hot ($T = 1/\beta$) and dense medium is given by :

$$\frac{dN_{l\bar{l}}}{d^4x d^4q} = -\frac{\alpha^2}{6\pi^3 M^2}\,\frac{1}{e^{\beta q^0} - 1}\,g_{\mu\nu}\,\left(-\frac{1}{\pi}\,Im\Pi_V^{\mu\nu}\right) \tag{6}$$

where M ($M^2 = q_0^2 - \mathbf{q}^2$) is the invariant mass of the produced pair. Once the overall thermal factor has been extracted, the DPR is directly proportional to the imaginary part of the current-current correlation function :

$$\Pi_V^{\mu\nu}(q) = -i \int d^4x \, e^{-iqx} \, \langle\langle J^\mu(x), J^\nu(0)\rangle\rangle(T, \rho_B). \tag{7}$$

For simplicity, we will concentrate on the (prevailing) isospin $I = 1$ (isovector) projection of the electromagnetic current, which is the dominant contribution from the interacting fireball :

$$\mathcal{V}_\rho^\mu = \frac{1}{2} \left(\bar{u}\gamma^\mu u - \bar{d}\gamma^\mu d\right). \tag{8}$$

It just coincides with the third component of the conserved vector current of chiral symmetry (see eq.1). We know from the well established Vector Dominance phenomenology (VDM) that the corresponding correlator is accurately saturated by the rho meson. This property is formally incorporated through the famous field-current identity $\mathcal{V}_\rho^\mu = (m_\rho^2/g_\rho)\,\rho^\mu$. Hence dilepton production allows to reach the imaginary part of the rho meson propagator, namely the in-medium rho meson spectral function. To have some insight about manifestations of chiral symmetry restoration this vector correlator should be studied simultaneously with the axial-vector correlator in which the properties of the chiral partner of the rho meson, namely the a_1 meson, are encoded. In the vacuum the SCSB manifests itself in the marked difference between the ρ and the a_1 and the transition from the hadronic to the partonic regime ("duality threshold") is characterized by the onset of perturbative QCD around $M_{dual} \simeq 1.5$ GeV. In the medium, full chiral symmetry restoration requires the degeneracy of vector and axial correlators over the entire mass range.

Density expansion. Several approaches have been put forward to determine the spectral properties of vector mesons in the medium. One method, very usual in nuclear physics, is the low density expansion :

$$\Pi^{\mu\nu}(q, T, \mu) = \Pi_{vac}^{\mu\nu}(q) + \sum_h \rho_h \, \Pi_h^{\mu\nu}(q). \tag{9}$$

Taking the imaginary part, one obtains the contribution of hadron species h present with density ρ_h to the spectral function. The vacuum piece is extremely well known from e^+e^- annihilation. The hadronic part is expected to be dominated by the lightest meson (π) and baryon (N). In the chiral reduction formalism [11], the hadronic matrix elements ($\Pi_h^{\mu\nu}$) can be inferred from a combination of empirical information (πN, ρN or γN data...) and chiral Ward identities. Although model independent in spirit, this framework does not allow to perform systematic resummations. Indeed it has the tendency to overestimate the rho meson peak itself because these higher order many-body effects are absent. Nevertheless this approach explicitly contains the already mentioned axial-vector mixing that we will now discuss.

Axial-Vector mixing. In the medium the emission and the absorption of thermal (finite temperature) or virtual (finite density) pions is able to transform a vector current into an axial current. In other words, the response of the system to a vectorial probe contains an axial contamination mediated by the pions, the pure vector piece being quenched by the emission and absorption at the same point. Hence increasing temperature or density (*i.e.* increasing the pion scalar density) makes the axial-vector mixing more and more important until full restoration where axial and vector correlators become identical. This mixing has been formally proven at finite temperature in the chiral limit, using only chiral symmetry. The finite temperature correlators are described to order T^2 by the following mixing of zero-temperature correlators [12]:

$$\Pi_V^{\mu\nu}(q;T) = (1-\epsilon)\,\Pi_V^{\mu\nu}(q;T=0) + \epsilon\,\Pi_A^{\mu\nu}(q;T=0) \tag{10}$$
$$\Pi_A^{\mu\nu}(q;T) = (1-\epsilon)\,\Pi_A^{\mu\nu}(q;T=0) + \epsilon\,\Pi_V^{\mu\nu}(q;T=0) \tag{11}$$

where $\epsilon = T^2/6f_\pi^2$ is directly proportional to the scalar density of the thermal pions. This implies that, to this order, the masses of the ρ and a_1 meson do not change although the order parameters (quark condensate and pion decay constant) are modified in contradiction with the BR scaling law. It is amusing to note that full mixing $\epsilon = 1/2$ corresponding to full symmetry restoration is realized at $T \simeq 160$ MeV very close to the lattice critical temperature. The above result has been extended beyond chiral limit in the chiral reduction formalism [11] in which the DPR writes :

$$\begin{aligned}\frac{dR}{d^4x d^4q} = &-\frac{\alpha^2}{\pi^3 q^2}\frac{1}{e^{\beta q_0}+1}\left[Im\,\Pi(q^2) - \frac{2}{f_\pi^2}\int \frac{d\mathbf{k}}{(2\pi)^3}\frac{n(\omega_k)}{\omega_k}\,Im\,\Pi_V(q^2)\right.\\ &\left. + \frac{1}{f_\pi^2}\int \frac{d\mathbf{k}}{(2\pi)^3}\frac{n(\omega_k)}{\omega_k}\left(Im\,\Pi_A((q+k)^2) + Im\,\Pi_A((q-k)^2)\right) + ...\right].\end{aligned} \tag{12}$$

The first term corresponds to the full electromagnetic correlator (with ρ, ω and ϕ pieces) and the second term exhibits the quenching of the (isovector-)vector correlator. The last term represents the axial-vector mixing beyond the soft pion limit ($k \to 0$). The integration over all the pion momenta yields a broadening of the (rho meson) spectrum which has to be understood as an unavoidable consequence of partial chiral symmetry restoration.

QCD sum rules. The QCD sum rule approach aims at an understanding of physical current-current correlation functions in terms of QCD by relating the observed (or calculated) hadron spectrum to fundamental condensates C_n (quarks, gluons) *i.e.* to the non-perturbative QCD vacuum structure. For large space-like momenta ($Q^2 = -q^2$), OPE techniques lead to :

$$\frac{\Pi(q^2=-Q^2)}{Q^2} = \int_0^\infty \frac{ds}{s} \frac{\left(-\frac{1}{\pi}\right) Im\,\Pi(s)}{s+Q^2} = \frac{d_V}{12\,\pi^2}\left[-C_0\, ln\left(\frac{Q^2}{\mu^2}\right) + \frac{C_1}{Q^2} + \frac{C_2}{Q^4} + \frac{C_3}{Q^6} + ...\right] \tag{13}$$

I will not discuss here the technical difficulties and limitations of the method which can be applied both in the vacuum and in the medium. I will only emphasize that it provides a crucial test of consistency between hadronic correlators and fundamental properties such as chiral symmetry and its restoration. Although such a test should be systematically done, the approach is only of little predictive power. It has been found [13,14] that the generic decrease of the quark and gluon condensates on the right-hand-side is compatible with the phenomenologically left-hand-side if either (a) the vector meson masses decrease (together with small resonance widths as in the ω meson case) or (b) both width and mass increase (as found in most phenomenological models for the ρ meson).

Dropping mass scenario. Early QCD sum rule analysis based on a sharp ansatz for the vector mesons [15] gave a decrease of the vector meson (rho and omega) of about 20% at normal nuclear matter density. At this time this result has been understood as being in favor of the scaling law proposed by Brown and Rho [6] on the basis of broken scale invariance in QCD :

$$\frac{f_\pi^*}{f_\pi} = \frac{m_\sigma^*}{m_\sigma} = \frac{m_\omega^*}{m_\omega} = \frac{m_\rho^*}{m_\rho} = \left(\frac{<\bar{q}q>^*}{<\bar{q}q>}\right)^{1/3} . \tag{14}$$

The rho mass itself plays the role of an order parameter. Although these scaling laws contradict some low density results, chiral symmetry does not forbid the vanishing of the mass at full restoration. But, as already discussed, such a dropping mass scenario is certainly not a necessary consequence of chiral symmetry restoration. Although this scenario yields a reasonable agreement with data [16,17], other hadronic many-body approaches containing other aspects of chiral symmetry restoration without dropping mass are also able to reproduce the data.

Many-body approaches. More conservative approaches reside on standard many-body techniques to calculate the self-energy and consequently the rho meson spectral function. They are based on effective hadronic Lagrangians possessing chiral symmetry and incorporating vector dominance. The various parameters (coupling constants and form factor cutoffs) are constrained as much as possible by other data and phenomenology (decay rates, photoabsorption, ρN scattering [18],...). One is thus able to evaluate the in-medium modification of the rho meson from its coupling to the various many-body excitations of the dense and hot matter from which one gets the DPR at a given temperature and baryonic chemical potential. As we will see below, once various final state hadronic decays are incorporated on top of the interacting fireball contribution, such an approach is able to reproduce the enhancement of the DPR below the ρ/ω peak and the apparent depletion of the peak itself. The latter depletion has a pure many-body origin : the propagator formalism generates resummations to all orders which are totally absent in any kind of low-density expansion and/or in incoherent summations of various processes. The total thermal yield in heavy-ion reactions is obtained by a space-time integration over the density-temperature profile for a given collision system modeled within transport or hydrodynamics simulations. Another very successful attempt is provided by a simple expanding thermal fireball [19] allowing to incorporate in a rather simple way hadronic many-body effects which are needed to obtain a consistent description of the data. In the most recent calculation for 158 A GeV Pb-Au collisions [20], the trajectory starts at $(T, \rho_B)_{in}$=(190 MeV, 2.55ρ_0), goes through the experimentally deduced point in hadro-chemical analysis [21] up to thermal freeze out $(T, \rho_B)_{fo}$=(115 MeV, 0.33ρ_0). These medium effects have been also compared with data for 40 A GeV Pb-Au collisions [22]. Transport calculations, where no assumption is made about the degree of thermalization, also get better agreement with data once in-medium spectral function is incorporated [23]. It is convenient at least qualitatively to separate temperature and baryonic density effects.

In a hot meson gas the first medium effect is the Bose enhancement of the $\pi\pi$ annihilation or, in terms of the rho meson propagator, the temperature effect affecting the two-pion loop contribution to the rho self-energy. In addition ρ-meson scattering, in first rank $\rho\pi \to \omega, a_1$, also significantly contributes to the rho self-energy. It is important to notice that the a_1 piece is of axial-vector mixing nature and the corresponding contribution to the DPR can be seen as a consequence of partial chiral symmetry restoration.

Historically the first advocated baryonic density effect was the medium modification of the two-pion loop through p-wave coupling of the pion to Δ-h states. This effect, usually referred as the pion cloud contribution, gives a significant enhancement of the DPR below the rho peak [24] and is mainly related to the coupling of the rho to dressed pions and Δ-h states (the so-called pisobars). Again, the very important point is that it contains an explicit mixing between the vector and the axial baryonic current, as recently demonstrated [5]. Finally, the direct coupling of the rho to baryonic resonances having sizable coupling to the rho has been incorporated. In a many-body language the rho couples to $N^* - h$ excitations building up the so-called rhosobars [25]. Among them the $N^*(1520)$ plays a prominent role (since the coupling is of s-wave nature) and gives a very important contribution to the low mass enhancement [26]. Contrary to the case of the a_1 and pion cloud contributions, the connection with chiral symmetry restoration of the $N^*(1520)$ is not transparent. The resulting full spectrum which incorporates all the above effects within the expanding fireball model nicely accounts for the 158 A GeV data (see full curve of fig.2), as well as for the 40 A GeV data [22]. A very important observation is that this spectrum is very flat and very close to a pure perturbative quark-gluon spectrum (see long-dashed curve of fig.2). One possible conclusion is that chiral symmetry restoration manifests itself as a lowering of the quark hadron duality threshold from its free space value of 1.5 GeV down to 0.5 GeV near the phase boundary [20].

Some final comments. We have seen that convincing arguments based on detailed calculations yield to the conclusion that dilepton spectra in relativistic heavy-ion collisions probing the phase transition region constitute a possible signature of chiral symmetry restoration associated to a lowering of the quark-hadron duality threshold. Nevertheless it is clear that a strong effort has to be pursued to improve theoretical analysis in connection with present and forthcoming experimental data. For instance, the connection of the resonance contribution (especially the $N^*(1520)$) with chiral symmetry restoration and axial-vector mixing remains to be fully elucidated although some suggestions have been proposed [28]. In addition, on a more practical side, the precise contribution of the omega meson should be separated to isolate the interesting medium effects relative to the rho meson channel. In that respect forthcoming high resolution data at CERN/SPS (NA60, CERES/TPC) and in a more baryon-dominated regime will certainly bring crucial information. In particular dilepton data obtained with the HADES detector at GSI will be of utmost importance for studying in the most favorable regime the baryonic medium effects which already seem to play a dominant role in the CERN/SPS regime.

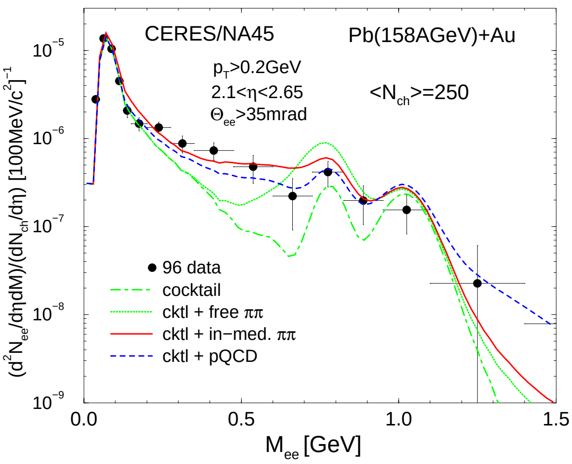

FIG. 2. Dilepton invariant mass spectrum measured in central 158 AGeV Pb+Au collisions compared to theoretical calculations [20]. The dashed-dotted lines correspond to the hadronic cocktail (without ρ decays), the dashed lines to the hadronic cocktail plus free $\pi\pi$ annihilation and the solid lines incorporate medium effects in the rho meson propagator (many-body approach). The long-dashed line is an exploratory calculation using lowest order $q\bar{q} \rightarrow ee$ annihilation rates only within the same expanding thermal fireball.

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